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Productivity of Skidders in Selection Cuts of Southwestern Ponderosa Pine

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Productivity of five skidders differed substantially among machines and operators and was not highly predictable. Reasonable regression equations for productivity could not be developed. Actual volumes carried per turn were far below theoretical maximums. Possibilities for maximizing productivity include increasing volume carried per turn and decreasing delay time.

Keywords: Skidding (tractor), logging, timber harvesting costs.

Both forest industry and the USDA Forest Service would like to increase residual timber value by minimizing timber harvesting costs. Since yarding is the timber harvesting operation that varies the most in productivity, it seems the logical place for potential reductions. In the central and southern Rocky Mountain areas, nearly all yarding is done with tracked or rubber-tired skidders.

For all conventional Forest Service timber sales, a skidding cost is determined before the timber is offered for bid. In Forest Service Region 3 (Arizona and New Mexico), skidding cost estimates are derived from regional average cost, with adjustments for deviations in volume per acre, volume per piece, uphill and downhill skid distance and slope, and defect deductions (USDA FS 1972). This Note discusses means for improving skidder productivity rather than presenting alternative procedures for estimating skidding costs.

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Considering Operations Theoretically

A basic premise in analyzing skidder productivity is that the skidder operator will attempt to maximize production over time while meeting the constraints imposed by safety considerations and good cleanup. Employees paid by the hour, as most skidder operators are, do not have a direct incentive for maximizing production. Good supervision and the desire to "please the boss," however, should provide an indirect incentive. But even if all skidder operators were equally motivated and supervised, individual skills would create differences in productivity. Previous research has found that 30 to 40 percent of production variation may result from differences in operator skill and motivation (Bennett and Winer 1964, Bartholomew et al. 1965). Cottell et al. (1971) found that the efforts of the skidding crew apparently varied in response to different physical, physiological, and psychological conditions. Another study (Cottell and Winer 1969) concluded that operator influences on productivity become more acute as mechanization increases. If we can account for this variation in operation skills, it should be possible to predict

maximum productivity, given the characteristics of the skid tractor, timber, and terrain. Characteristics of the skid tractor that must be considered are the drawbar or pulling power, running speed in each gear, and slippage of wheels or tracks. Timber characteristics include volume per piece, volume per tree, pieces per acre to be skidded, and density of the residual stand. Terrain factors include skid distance, steepness of slopes over which timber is skidded, and surface condition of the ground. Gardner (1968) and Schillings (1969) indicated that the primary factors affecting productivity of crawler tractors are average skid distance, soil and surface characteristics, slope, operator efficiency, fixed time per turn, and volume per turn.

In examining skidder productivity and potential for improvement, the skid cycle time may be divided into outbound (away from deck) time, bunch and hook time, inbound (to deck) time, unhook time, decking time, and delay time.

Outbound time is a function of distance and rate of travel. Operators have long recognized that distance from tree to log deck affects skidding productivity even though the exact relationship is not known. One study concluded that the speed and versatility of the rubber-tired skidder may have downgraded the importance of skid distance over a normal operating range (Bennett et al. 1965). The actual effect of distance is determined by the interaction with the other variables. Speed rate is affected by surface condition and slope, and can be limited by rocks, timber density, and brush that makes locating logs difficult. **Inbound time** is affected by the same variables; in addition, inbound speed can be affected by weight of the load being skidded. In general, skidder speeds (particularly outbound speeds) are limited by safety and operator comfort rather than power. Previous investigators have also reached this conclusion (Phillips and Spray 1966).

Bunch and hook time are affected by volume per piece and distance between felled trees. These factors influence bunch and hook time for both grapple and cable skidders, although the exact effect is different for each skidder type. For grapple skidders, location of the log with respect to the skid trail has relatively more effect, since the grapple skidder must travel to each log. Travel between trees while bunching and hooking can also be affected by terrain, surface condition, and timber density. **Unhook time** is usually constant for a grapple skidder. For cable skidders, unhook time is a function of the number of pieces skidded, or number of chokers used if there are two or more pieces per choker. **Decking time** is a function of volume per deck and height of deck. Generally, average time per turn spent decking will increase with deck height and size. **Delay time** includes all time spent idle due to breakdowns, fueling, personnel breaks, and waiting in queues at the log deck. Skidder breakdowns can be minimized by preventive maintenance and careful operation. Waiting time at the log deck can be minimized by having skidder operators drop their loads at an alternative location close to the log deck if there is another skidder at the deck (providing one or more of the skidders is a grapple skidder so the load can be easily regrappled and moved when the deck area is clear).

Optimum skidding production is achieved when volume per unit of total skid cycle time is maximized. Maximum production per unit of time under any given situation can be obtained by maximizing the volume skidded per unit of inbound time where distances between harvested trees are not great. This maximum will occur at the lowest gear of the skidder, assuming the log load is also the maximum the skidder can carry. If speed is doubled, for example, more than half of the available skidding power is lost. Sacrificing load size to increase speed therefore reduces volume per unit of inbound time and productivity. Cost per unit of volume skidded will be minimized when volume per unit of inbound time is maximized.

In practice, accelerating, traversing rough ground, avoiding obstacles, and slowing down for approaches to the log deck prevent traveling at the highest theoretical speed when loads are light. Lower speeds with heavier loads are more efficient. Attempting to achieve the absolute maximum weight that can be skidded, however, may result in higher hooking costs if time is spent searching for the right size logs, or in overloads that might cause equipment breakdown. For partial cuts, the increased distance between logs may become a limiting factor in hooking the maximum loads. In instances where short or small-diameter pieces are being skidded, the size of the grapple opening or the number of chokers will limit the load weight to less than maximum levels.

The maximum load for any given set of circumstances is difficult to determine. Knowledge is lacking on the actual coefficient of skidding resistance (coefficient of friction and resistance resulting from gouging action of the dragging logs), tractive efficiency of the skidder, and variation in slope from woods to landing or log deck, particularly as affected by skid road placement and alinement. However, by using assumptions for the above factors, a theoretical maximum load can be computed.

Load capacity depends to some extent on characteristics of the logs in the load and exactly how they are skidded. Garlicki and Calvert (1968)

found that for tree lengths, less power was needed if logs were skidded butt first with the butt end suspended. They also found that skidding whole trees consumed twice as much power as skidding tree-length logs (Garlicki and Calvert 1969).

Analyzing Skidder Productivity

During the summer of 1973, time and motion data were taken on five skidders in Arizona (table 1). Saw logs and pulpwood from a selection cut on a ponderosa pine site were being skidded and decked together. All skidders were intermediate size (90-140 net flywheel horsepower). Machines 1, 2, and 3 were rubber-tired skidders with grapples; machine 4 was a crawler with chokers; and machine 5 was a rubber-tired skidder with chokers. Four machine operators had at least one season's experience; operator 5 had only 2 weeks' experience. Skidders 1 through 4 were skidding to the same log deck. Skidder 5 was operating in the same timber type, but was not part of the regular crew and was skidding to a separate log deck.

To determine theoretical capacity, detailed data were taken on skidders 1 and 2. Both skidders operated in the same type of terrain and close to each other. Skidder 1 was rated at 120 net flywheel horsepower; skidder 2 at 94. Based on data in table 1, skidder 1 averaged about 510 ft^3 per working hour, and skidder 2, about 270. Differences in productivity were partly due to power differences between machines and partly to differences in operator performance. Skidder 1 passed up some small logs in favor of hauling larger and more distant logs, while skidders 2 and 3 brought in the remaining logs and in general worked the areas containing smaller timber. Timber on steep pitches or otherwise hard to harvest was left for the crawler (skidder 4) since it was the only one of the four skidders with chokers. Generally, these difficult areas were farthest from the roads.

Variables measured for each turn included: (1) travel time and distance from the log deck to the location of the first log picked up for that turn, (2) time spent and distance traveled grappling and traveling between logs, (3) inbound time and distance from the last log grappled or hooked to the log deck, and (4) time spent decking or piling logs. Delay time during each turn was also recorded. For each part of the skidding cycle — outbound, hook, and inbound time — data were taken on average slope, surface type (obstacles to skidding), surface condition (dry, wet, and so forth), and brush density. For each turn, the length of each log with the diameters of each end were measured, and the approximate cubic volume of wood was computed using the formula for a frustum of a cone.

Data were taken on separate turns to avoid using data for load volumes and skid distances averaged over a period of time. Obviously, delay time and deck time do not occur on every turn and are subject to a very high variance if computed on a turn basis. Therefore, only outbound time, hookup time, and inbound time (exclusive of obvious delays) were included in the regression analysis.

Table 1.--Average value of variables for five skidders yarding sawtimber and pulpwood on the same site in Arizona, 1973

Skidder and type	Distance traveled			Volume		Travel speed		Time				Turns		Productivity/ working hour	
	Outbound	Hooking	Inbound	Per skid turn	Per piece	Empty	Loaded	Hook time/ piece	Delay time/ turn	Deck time/ turn	Total time/ turn	Total/ hour	Pieces/ turn	Pieces	Volume
	- - *Yards* - -			*ft*^{3}		*m/h*		- - - - *Minutes* - - -				- *No.* -		*No.*	*ft*^{3}
SKIDDER 1 (rubber-tired; grapple)	76.6	42.0	88.7	75.2	25.2	2.0	2.4	1.0	2.8	0.6	8.8	6.8	3.0	20.0	510
SKIDDER 2 (rubber-tired; grapple)	57.7	18.6	54.8	39.7	14.3	1.8	1.8	1.0	3.5	.6	8.8	6.8	2.8	19.0	270
SKIDDER 3 (rubber-tired; grapple)	108.6	41.5	100.7	34.8	11.5	1.9	2.9	1.7	4.7	.8	13.7	4.4	3.0	13.3	150
SKIDDER 4 (crawler; choker)	177.1	43.8	186.3	87.9	16.3	1.4	1.6	1.4	9.6	1.1	26.6	2.3	5.4	12.1	200
SKIDDER 5 (rubber-tired; choker)	91.8	7.7	75.8	55.1	21.1	1.5	2.0	1.6	1.6	1.7	10.9	5.5	2.6	14.4	300

Independent variables that were significant in predicting time per turn included inbound distance, distance traveled while hooking logs, slope percent in the areas where logs were being hooked, and a subjective rating from 1 to 3 based on increasing obstacles to travel (rocks, down timber, and so forth). The regression coefficient of determination (R^2) was not acceptable for some skidders. R^2 values ranged from 0.43 to 0.71. No method for determining independent variable values was consistently reliable. This, coupled with wide and unpredictable variations in volume per turn, rendered the prediction equations unreliable.

Improving Productivity and Reducing Skidding Costs

If average productivity of each skidder is used as a gage, possibilities for improving productivity become apparent. Some skidders operate erratically, particularly with regard to volume skidded during any particular turn (see table 1). Skidder productivity could be improved by making and enforcing some general operating rules.

Some of the variables, however, reflect conditions that the operator cannot control. For example, volume per piece cannot be increased on the area as a whole unless bucking to longer lengths were possible. Likewise, skidding distance cannot be changed unless options exist for spacing log decks and/or spur roads closer together, as discussed later. Remaining major means of increasing productivity, then, are decreasing hook time per piece, reducing delay time, and increasing volume per turn.

Since hook time is determined primarily by location of the log with respect to the skid trail, residual stand of surrounding timber, and the local terrain, few chances for improvement exist. However, the practice of one skidder searching out only big logs increases distance traveled hooking — a practice which probably increases total hook time for all skidders in the crew and the likelihood that some logs will be missed. For cable skidders operating on short distances, employing a chokersetter to preset chokers may be practical to reduce the operator's hooking time. Chokersetters were not being used on the operation we evaluated, however.

Delay time occurs when skidders either wait for another skidder to clear the deck area or they stop enroute to chat about the location of logs yet to be skidded. With grapple skidders, time could be saved by dropping the load and regrappling it later when the deck area is clear instead of waiting for access to the deck. A clear decking strategy and protocol should prevent most delays at the deck. Delays to discuss the location of remaining logs could be avoided by assigning each skidder to a designated sector. This would also allow each operator to mentally build his next load as he is bringing in the current one, since no logs would be removed from the immediate area before he returned. Operator 5, who was skidding in a location away from the other skidders, had the least delay time even though he was inexperienced (see table 1). This illustrates the need for more planning in design of landings and the associated skidder traffic pattern.

How much the volume per turn could have been increased cannot be inferred from the data. Skidders 1 and 2 appeared to be hauling loads far below capacity (fig. 1) as well as far below the theoretical maximum volume for the slope. The 50 percent theoretical maximum load that could have been skidded by each machine for given speeds for these same slope classes assumes a coefficient of skidding resistance of 0.70 and a weight of 59 pounds of wood plus bark for each cubic foot of solid wood. Average volumes per load by slope class (fig. 1) indicate no apparent relationship between what could have been skidded and what actually was. The operators may have had one or more of these problems: (1) did not know their maximum load capacity, (2) did not know the weight of the load they had grappled at any particular time, (3) could not find enough logs in one location to make a larger load, or (4) were not concerned about maximizing the load. Providing operators with estimating aids and with more training should help overcome the first two problems. The third problem would be partially solved by assigning skidders to sectors, but more research is needed to determine the relationship of log size and log density to the optimum load for a given skidder. For various spatial distributions of logs, guidelines are needed to determine when to bring in a light load instead of searching for additional logs to bring the load closer to the maximum weight.

The fourth problem, lack of motivation, undoubtedly exists to some degree in all harvesting crews. Adequate training may increase crew member motivation by creating an aura of professionalism, although this has not been proven. Other more direct incentives may be required.

Although most of the concern above has been with skidders carrying far less than their capacity, overloading can result in equipment breakdown and costly delays. For properly maintained equipment, however, improper use such as jerky starts or excessive speeds is more likely to cause breakdowns than overloading.

Pay incentives for skidder operators, based on volume or number of pieces, would help overcome lack of concern over productivity, but this

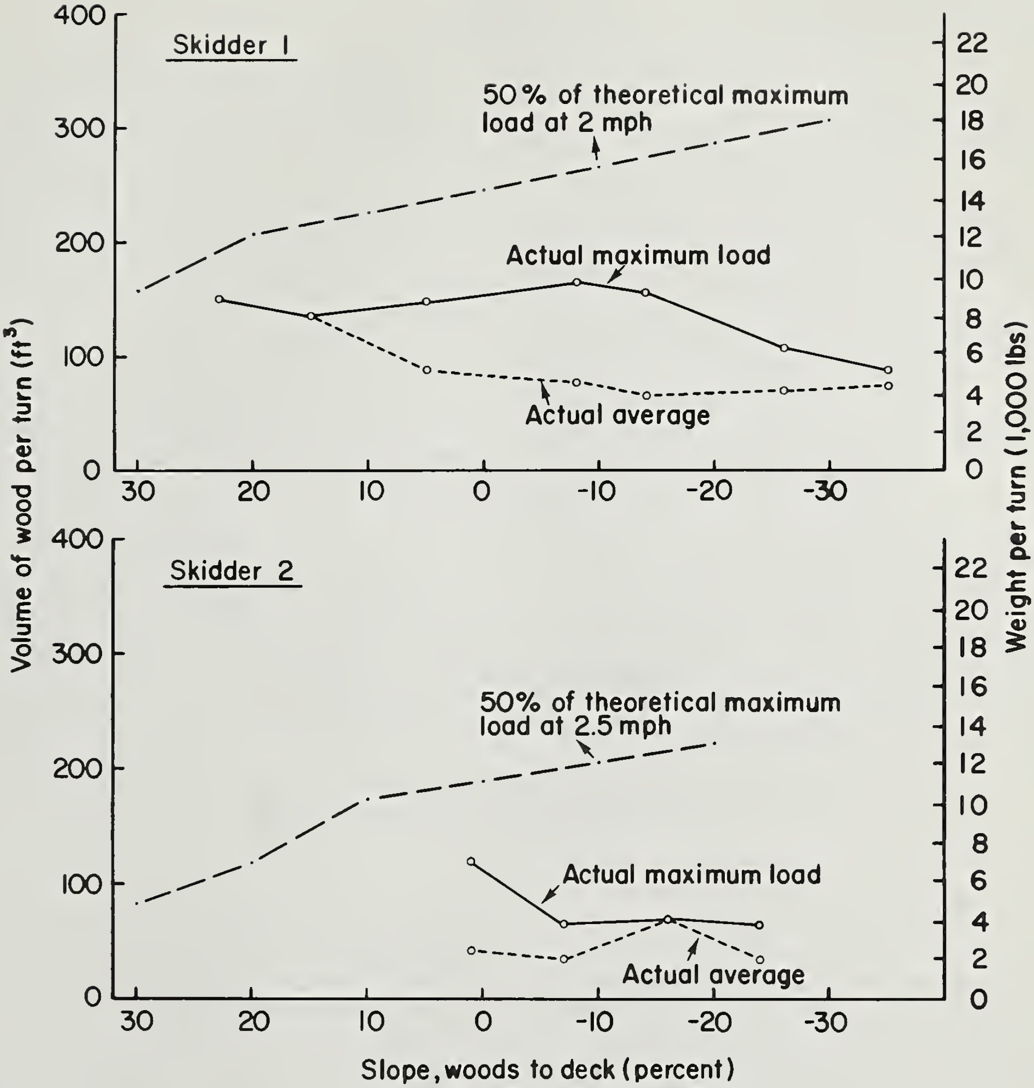

Figure 1.—Loads per turn for two skidders, with theoretical maximum, actual maximum, and average volume by percent slope.

approach is not common in the central and southern Rockies.

The above discussion pertains to improving skidding productivity on an ongoing timber sale where roads were already located, and road costs were not considered. In practice, the goal is actually to minimize the unit cost of skidding plus road construction. The general relationship between skidding costs, road construction costs, and the total of the two is shown in figure 2 for gentle terrain where road location is optional. Distances that skidders actually travel are affected not only by road spacing, but also by deck spacing along the road and the efficiency with which skidders travel between log decks and timber to be skidded.

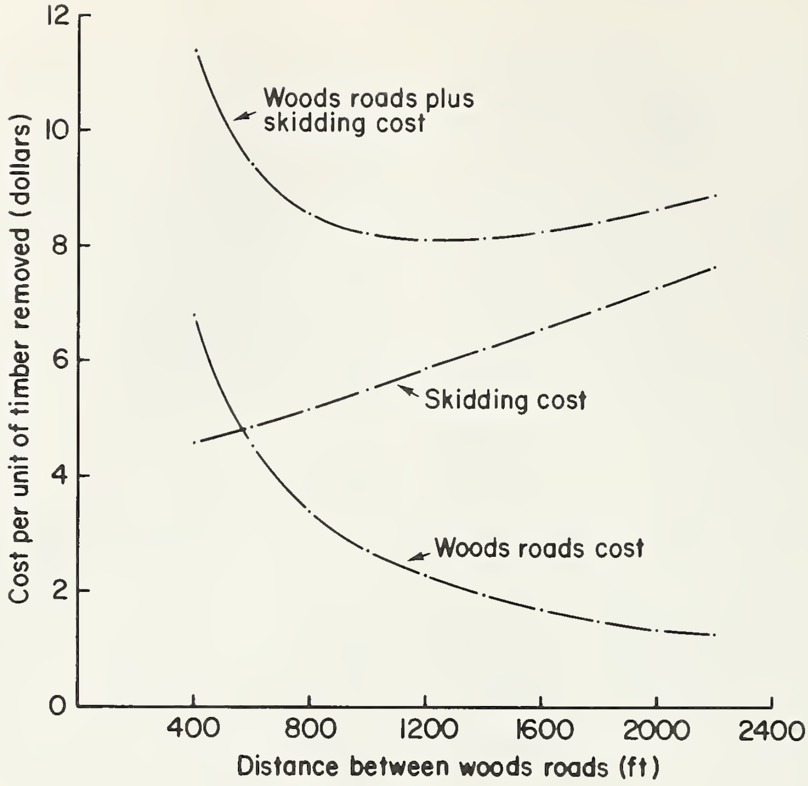

Figure 2.—General relationship of skidding costs to construction and spacing of woods roads for a hypothetical situation.

Summary and Conclusions

Given the pertinent skidder characteristics of weight, power, and traction plus precise data on slope, size distribution, and spatial distribution of the timber to be skidded, the time per turn, volume per turn, and volume per hour become precisely determinable. However, for most logging chances, determining values for all of the above independent variables is not practicable.

To investigate skidder productivity, data were taken for four rubber-tired skidders and one crawler skidder that were yarding selection-cut ponderosa pine. Detailed data were taken for two of the rubber-tired skidders that were equipped with grapples. One skidder was rated at 120 and the other at 94 net flywheel horsepower. Regression equations developed for each of the skidders from data taken on a turn basis did not satisfactorily predict performance. Part of this could be attributed to skidder operators who did not perform consistently, although they seemed to be typical of operators observed on other areas. The operator of the larger skidder tended to search out the largest pieces and, hence, traveled greater distances and carried larger loads. Both skidders carried loads far below the theoretical maximum, part of which could be attributable to the spatial distribution of the timber.

Major opportunities for increasing skidder productivity appear to be (1) increasing the volume carried per turn, and (2) decreasing delay time. Operators should know the general volume range that their machines are capable of skidding over any given type of terrain. They must also be able to estimate the volume that they have hooked or grappled at any particular time, and the likelihood of finding one or more logs nearby that can be skidded without overloading. If greater volumes per turn are not possible due to spatial distribution of timber on the site, smaller, less expensive skidders may be able to maintain the same productivity, but at a lower cost per unit of volume.

The most common delays were skidders interfering with each other both in the field and at the log deck. These delays could be minimized if skidders were assigned to different sectors, and if operators were instructed to drop their load nearby when the landing was occupied.

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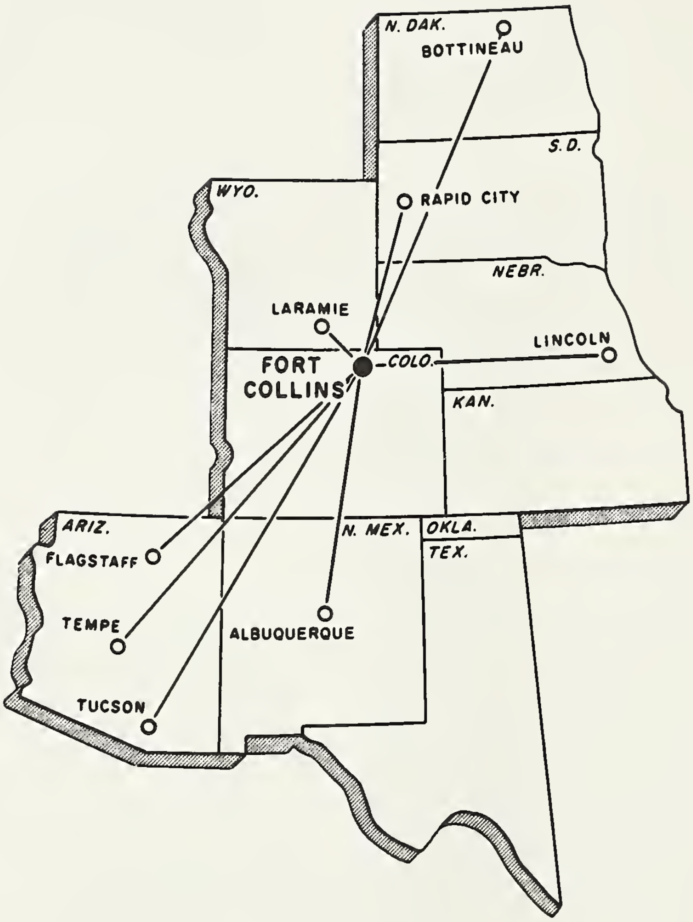
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